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FORMATION AND CHARACTERIZATION OF ALUMINIUM METAL MATRIX NANOCOMPOSITES

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ABSTRACT

In the new era of competitive world, need has been increased tremendously for the development of lightweight, low cost, an efficient, corrosion resistive, high reflectivity, tough conducive materials. Many researchers have used aluminum alloys to investigate the effects of added alloys on various properties of the material. Pure aluminium is a weak, soft and ductile material, but adding a small amount of impurity in aluminium, its properties such as tensile strength and hardness can be increased considerably. Aluminum alloy composites are better in thermal expansion coefficient, corrosion resistance, wear resistance and other mechanical properties. Metal matrix composites are advanced materials, which combine reinforcement materials to produce composite materials, which are designed to obtain different properties like stiffness, impact resistance or use in high temperature environments. Nanocomposite is emerging as advanced materials with high strength for the industrial applications that have capacity to satisfy recent demands of advanced engineering applications. In this paper, an emphasis is given on collecting, analyzing and concluding very vast amount of work on the formation and characterization of metal matrix composites and nanocomposites and to find out gaps in recent related research and developments.

KEYWORDS: Formation, Characterization, Aluminium, Composites & Nano Composites

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Original Article

INTRODUCTION

The application of an advanced material may be the key to revolutionizing a product line and keep pace with accelerated market change and technology developments. The aluminium metal matrix nanocomposites are high-performance low-weight alloys that have the capacity to replace use of traditional materials in advanced applications. These composites can provide unique combination of material properties like high-specific strength, high-specific stiffness, very low density, improved dimensional stability and higher wear resistance. Aluminium metal composites are finding widespread applications in aircraft, marine, engineering, automobile, aerospace and defense and recreation industries etc.

Nanocomposites are usually nanosized particles or nanoscale structure and fibers to improve mechanical strength, toughness and electrical or thermal conductivity. We can expect superior capacities and remarkable enhancement in various properties in nanocomposites as compared to traditional materials. Here, emphasis is given on the nano-structured aluminium metal matrix composites because of their unique mechanical properties.

LITERATURE REVIEW

Literature Survey of the Research Area

Following are the recent research literature, which give valuable information about nanocomposites, aluminium, aluminium alloy, properties, methodology and technology for preparation of nanocomposite material. Etc

Table 1

Sr. No.	Paper Title	Authors (Country), Journal, Publisher	Content/Review	Remark (Methodology/Material)	Gap
1	The fabrication of graphene - reinforced Al - based nanocomposites using high - pressure torsion.	Yi Huang, Piotr Bazarnik *et. al.*(UK), journal of Acta Materialia 164 (2019) 499–511, Elsevier publications	Fabrication of graphene-reinforced nanocomposite can be achieved by HPT, i.e., high-pressure torsion. Nanocomposites of graphene reinforcement develops better material strength of Al base alloys. A microstructural analysis shows the distribution of graphene in the Al matrix alloy. The results indicate processing by HPT, i.e., high pressure torsion is advantageous and avoids the sintering and high temperature deformation observed by other processing methods.	H. P. T., Hitachi SU-8000 SEM, Tensile testing	Specific applications are not defined.
2	A study of the dynamic compressive response of $AZ31/Al_2O_3$ nano-composites and the influence of nanoparticles	Y. Chen, Y. B. Guo, M. Gupta, V. P. W. Shim (Singapore), International Journal of Impact Engineering 89 (2016) 114 – 123, Elsevier publications	The variable compressive mechanical behavior of magnesium alloy AZ31 based nano-composites are investigated using a Split-Hopkinson pressure bar. The key research findings are 1). The small amount addition of nanoparticles of aluminium oxide (Al_2O_3) does not create any positive influence on the compressive ductility of monolithic magnesium alloy AZ31. 2) The influence of strain rate on the flow stress of monolithic magnesium alloy AZ31 nano-composites is significant.	Split- Hopkinson bar device, XRD, Fractography	Effect of other reinforcing element need to investigate
3	High performance cutting of advanced aerospace alloys and composite materials	Rachid M'Saoubi, Dragos Axinte, *et. al.*(UK), Journal of CIRP Annals - Manufacturing Technology 64 (2015) 557–580, Elsevier publications	Europe's well-known Vision ''Flightpath 2050'' for Aviation sets goals as follows: (1) Reduction of 75% CO2 per passenger kilometer (2) Reduction of 90% in NOx emissions (3) Reduction of 65% in noise. This means lightweight composite materials and designs will require on airframes and engines.	Broaching tool for generating a dovetail profile, Orthogonal cutting of Inconel, Wear damages in drilling, Scoring in broaching etc explained.	Superior composite / nano - composites need to develop and need further investigation of their machining properties
4	Aluminium Alloys for Aerospace Applications	N. Eswara Prasad (DRDO, India) and R. J. H. Wanhill (Netherlands), Journal of Aerospace Materials and Material Technologies 2017, Springer publications	Unique combination of various properties makes aluminium alloy important for airframe structures. Foreign organizations dominating the Indian aerospace industries due to technological gaps between India and these organizations. High strength and modulus are major challenges to the use of Al alloys, which inherently suffer from low stiffness.	Detailed material information about various components of aircraft is provided	Significant improvements in strength, not achieved in conventional Al alloys.
5	Laser ultrasonic technology for residual stress measurement of 7075aluminum alloy friction stir welding	Yu Zhan, Yingmei Li *et. al.*(China), Journal of Applied Acoustics 145 (2019) 52 – 59,	Solid state joining process, i.e., friction stir welding (FSW) method used in the welding of aluminum alloys in aerospace applications shows high efficiency and good material properties. In this research article, the residual	Laser ultrasonic Technology, Prestress loading device.	Effect of tool tilt angle and plunge depth on maximum longitudinal residual stress should consider.

		Elsevier publications	stress in friction stir weld in aluminium alloy 7075 is measured by laser ultrasonic technique. Acoustoelastic constants are found out by prestress loading method. Results shown that the residual stress distribution is asymmetric and the residual stress on the advancing side is greater than that on the retreating side.		
6	Abrasive machining of advanced aerospace alloys and composites	Fritz Klocke, Sein Leung Soo, *et. al*.(Germany), Journal of CIRP Annals - Manufacturing Technology 64 (2015) 581 – 604, Elsevier publications	In this research, capability and developments of current technology with regard to grinding or abrasive machining of newly invented aerospace alloys and composite materials are presented. Material removal by Abrasive machining is a key process utilized and employed in the production of aeroengine components.	SEM, VIPER grinding, laser dressing, wire electrical discharge dressing, etc.	Need more investigation on various alloys
7	Mechanical properties of graphene and graphene -based Nano - composites	Dimitrios G. Ian A. Kinloch, Robert et.al.(UK) , Journal of Progress in Materials Science 90 (2017) 75–127, Elsevier publications	Researcher experimented on formation of graphene reinforced nanocomposite and evaluation of various properties associated. Exact property evaluation of mechanical characteristics within the graphene and graphene-reinforced material is carried.	Raman spectroscopy, mechanical properties evaluation	High-quality graphene production scale up is a major issue which affects ultimate properties
8	High-quality graphene directly grown on Cu nano - particles for Cu - graphene nanocomposites	Shuangyue Wang, Shaobo Han *et al*.(china) , Journal of Materials and Design 139 (2018) 181–187, Elsevier publications	Vacuum deposition method, i.e., chemical vapor deposition method is employed to grow high-quality graphene on the surface of Cu nanomaterial. The hardness of 2.53 GPa with no distinctive degeneration in electrical resistivity exhibits by nanocomposites.	Chemical vapor deposition (CVD)	Specific Applications should be focused
9	Research on susceptibility of 7075 aluminum alloy to extrusion welding	D. Lesnik, K. Zoborowaski *et al*. (Poland) Engineering Fracture Mechanics 97 (2013) 1–11, Elsevier publication	Testing of weld ability of the 7075 grade aluminum alloy is accomplished and presented by researchers. 7xxx series Primary drawback of aluminium alloys exhibit poor weldability, which results in low product quality, decrease in permissible exit speed of die and low production efficiency of die.	Authorial patented device Also the light microscope, SEM, ESD, etc used	High quality welds not obtained, relation between unit pressure and yield strength is not obtained.
10	Fabrication methods of particulate reinforced Aluminium metal matrix composite	N. Panwar, A. Chauhan, Materials Today: Proceedings 5 (2018) 5933–5939. Elsevier publication	This research provides following information as (1) Classification of fabrication method took place in two distinct types. First is Solid phase processing and other is Liquid phase processing. (2) Liquid phase process consists of continuous stir casting process, compocasting process, squeezing casting process and spray casting processes and stirring by friction processing method and	(i) Solid state processing and (ii) Liquid state processing.	Experimental information is not provided

			powder metallurgy are solid-state processes. (3) Continuous stir casting is the easiest process and cost saving and provides uniform distribution of nanoparticles. (4) Powder metallurgy also can provide uniform distribution of particles but is a very costly process.		
11	Fabrication and characterization of Al2O3/aluminum alloy composites.	B. Kandpal, J. Kumar *et al.*, Materials Today: Proceedings 4 (2017) 2783 – 2792, Elsevier publication	(1) Fabrication method used is liquid state fabrication. (2) The microstructure analysis studied by scanning electron microscopy. It shows homogeneous distribution of Al2O3 particles in the aluminum matrix. Al2O3 particles cluster was observed in a few places. (3) Composites of reinforcement of Al2O3 particles improve the microhardness and ultimate tensile strength.	liquid state fabrication, scanning electron microscopy,	Need to define specific applications
12	Effect of Forging on Aluminum Matrix Nano Composites	R. Purohit, M. Qureshi *et al.* , Materials Today: Proceedings 4 (2017) 5357–5360, Elsevier publication	(1) Manufacturing process such as forging, deep rolling, extrusion of composites and other materials improve various properties in addition to the confirmation of the final shape and size. (2) Smooth metal flow and aligned grain flow pattern can be achieved by forging. (3) Best result of mechanical forging of Aluminium composites with Si-C particle reinforcement found at temperature between 450 and 500 degree Celsius.	forging, rolling, extrusion, Powder metallurgy	Necessary to check effect of other forming process on Aluminum Matrix Nano Composite Materials
13	Mechanical, Structural and Corrosive behavior of AlMg4.5/Nano Al2O3 Metal Matrix Composites	Chandrashekar A, B S Ajaykumar *et al*. Materials Today: Proceedings 5 (2018) 2811–2817, Elsevier publication	Research explores (1) formation of AlMg 4.5/aluminium oxide Al2O3 by different weight percentages by stir casting method. (2) The effect of nanoparticles on the evolution of microstructure analysis, material hardness and tensile properties is observed. (3) The hardness and tensile strength is considerably increased due to Al2O3 reinforcements. (4) The corrosion tests by % NaCl aqueous solution clearly shows that AlMg4.5/Nano Al2O3 composites exhibit excellent corrosion resistance than the pure Al matrix.	Stir Casting Process, microstructure testing, hardness testing and tensile testing, corrosion testing	Need test behavior of other composites
14	Silicon Carbide Reinforced Aluminium Metal Matrix Nano Composites	A Prasad Reddy, P. Krishna *et al.* Materials Today: Proceedings 4 (2017) 3959–3971, Elsevier publication	Mechanical and physical properties enhancement and interfacial characteristics achievement can be obtained by reinforcement of SiCp nanoparticles in aluminium alloy The reinforced SiCp nanoparticles are uniformly distributed, which can be seen in micrographs taken in micrographs in the matrix alloy.	scanning electron microscopy, Various mechanical and physical characteristic	Other properties are needed to evaluate

The papers analyzed in literature have touched all aspects of manufacturing, machining, formation and characterization, property evaluation of nanocomposites. Though there are various works or activities needed to take under the research, these various works or activities are raised in literature gap. Other research papers listed in the bibliography also provided valuable information of manufacturing, machining, formation and characterization, property evaluation in

more or less the same amount as presented in survey table, hence not mentioned separately.

Scope for Further Research (Gap Analysis)

The literature gap found in literature review is as follows:

- Specific applications of aluminium-based nanocomposites using high-pressure torsion are not defined.
- Investigation of the effect of various reinforcing elements on aluminium alloy is needed to carry out.
- Superior composite/nanocomposites need to develop and need further investigation of their machining properties.
- Significant development in material strength and specific elasticity is difficult to achieve in conventional Al alloys.
- Need more investigation of abrasive machining on various advanced composites/nanocomposites.
- More investigation is needed for graphite particles and metal matrix nanocomposite materials.
- Applications of high-quality graphene directly grown on Cu nanoparticles for Cu-graphene nanocomposites should be focused
- High-quality welds of 7075 aluminum alloy to extrusion welding is not obtained, and the relationship between unit pressure applied and yield strength is not obtained.
- Experimental information on fabrication methods of particulate reinforced matrix composite is not provided.
- Necessary to check the effect of other forming process on Aluminum Matrix Nanocomposites Materials
- Microstructural analysis of various nanocomposites need to be carried out.
- Mechanical and tribological properties of various nanocomposites are necessary to investigate.

RESEARCH METHODOLOGIES AND TECHNIQUES

Table 2

Sr. No.	Activity	Methodology
1.	Selection of nonmaterial for formation	Qualitative study properties of various nanomaterials
2.	Formation of nanocomposite alloy	Various casting techniques
3.	Characterization of physical properties	SEM, Visual inspection and Computations
4.	Characterization of Mechanical Properties	Tensile Testing, Hardiness testing
5.	Characterization of Microstructure properties	SEM
6.	Characterization of other required parameters	Suitable instrumentations

FABRICATION TECHNOLOGY

Fabrication technology of the nanocomposite materials is targeted on manufacturing materials with development in properties as compared to the metal matrix material. The important task in the processing of nanocomposites is to maintain homogeneous distribution of the reinforcement particles/fibres to achieve a zero defect or minimum defect microstructure. Primary processes for manufacturing of AMCs at industrial scale can be classified into two main categories: 1. Liquid phase processes, 2. Solid phase processes.

Liquid State Processes

Table 3: Liquid State Processes

Sr. No.	Process/ Technology	Application	Remarks/ Suggestions	Cost
1	Squeeze casting	Used for manufacturing all internal combustion engine components and other complex objects can be manufactured by this technology	Can be used for particle/fiber/plates reinforcement and used for large-scale manufacturing.	Medium
2	Spray casting	Applications of this technology are cutting and grinding tools, friction materials, etc	Particulate reinforcement used. Here, full density materials can be produced.	Medium
3	Stir casting	It is an economical and commercial method of producing composites and nanocomposites. It is applicable to mass production	Suitable for reinforcing fibers, particles, sheets in metal or ceramic matrix.	Very low cost and economical
4	Compo – casting	Used for manufacturing pumps, automotive and aerospace Industries	Suitable for reinforcing phases in metal matrix, especially discontinuous fibers/particle reinforcement.	Low
5	In-situ Processing	Transportation applications	To obtain uniform distribution of the reinforcing elements	Very High
6	Liquid phase infiltration	Used for manufacturing basic structural components such as beams, columns, trusses, rods, shafts cylinders, etc.	Can be used for particle reinforcement.	Low-to-medium cost

Solid State Processes

Table 4: Solid State Processes

Sr No.	Process/ Technology	Application	Remarks/ Suggestions	Cost
1	Diffusion bonding	Can be used to manufacture basic structural components	Sheets of metal matrix can be prepared	Very High
2	FSW - Friction stir welding	It can be used in pumps, automotive and aerospace applications.	Can be used in surface hardening or to improve wear resistance	Medium cost to high cost
3	PM - Powder Metallurgy	Powder metallurgy (PM) is an important process than other solid phase processes. It provides homogeneous and uniform distribution of nanoparticles in metal matrix material and used to producing small medium size to small size components and high-strength materials and heat-resistant materials.	In this formation process, powder of both matrix and reinforcements is employed. Effective for nanoparticle reinforcement. Greater strength composite can be prepared	Medium
4	Ultrasonic-assisted casting	Ultrasonic-assisted casting is favorable for mass production as it is an expensive process. It also can be used for net-shaped fabrication of components	Uniform distribution of reinforcement particles can be achieved.	High

NANO PARTICLES

The following are important nanoparticles each with their key properties.

Table 5: Nano Particles

Sr. No.	Types of Nanoparticles	Sub Types of Nanoparticles	Key Properties
1	Metal nanoparticles	Iron	Corrosion sensitive, unstable and reactive in nature
		Gold	Very reactive and reflective
		Silver	Light absorber, stable and anti-bacterial
		Aluminium	Highly reactive, temperature sensitive
		Zinc	anti-corrosive, antibacterial
		Copper	highly thermal and electrical conductive, ductile
		Lead	Toxic and stable
2	Metal oxide nanoparticles	Iron oxide	Corrosion sensitive, unstable and reactive
		Silicon dioxide	Less toxic, stable
		Aluminium oxide	Highly reactive, highly temperature sensitive
		Zinc oxide	Antibacterial, anti-corrosive
		Titanium oxide	Magnetic
3	Carbon nanoparticles	Carbon nanofiber	High electrical and thermal conductivity, good mechanical properties
		Carbon Nano Tubes	Flexibility, Elasticity and considerable strength
		Graphene	Extremely high strength, Ultralight, immensely tough, Flexible, compact structure, Transparent, thinnest material
		Fullerenes	Transmit light. Can be semiconductor and superconductor
		Carbon Black	Electrically and thermally conductive, good mechanical properties

CHARACTERIZATION OF NANOCOMPOSITE

The various characteristics of novel aluminium metal matrix nanocomposites are determined by using various technologies and methodologies as follows: Microstructure analysis of newly formed nanocomposite can be achieved using (SEM) scanning electron microscope, (TEM) Transmission electron microscopy, (XRD) X-ray Powder Diffraction to determine whether desired material properties are achieved or not.

Mechanical testing parameters like elasticity, stiffness, proof strength, yield strength, ductility, Ultimate Tensile Strength (UTS). The relationship between stress and strain (load and elongation), Hardness, Toughness can be evaluated by Tension Tests, Hardness Tests and similar tests.

CONCLUSIONS AND SCOPE FOR FUTURE WORK

The aluminium metal matrix composite materials have the capability to replace conventional materials in current applications. Generally, nanoparticles are synthesized broadly into three categories, as carbon-based, metal-based and metal oxide based nanoparticles consists of various nanoparticles in each family, respectively, each with distinct size and property. Reinforcement of these particles in metal matrix will give added predominant metal characteristics. Nanocomposite fabrication methods are grouped into solid phase processing and liquid phase processing. Stir casting, compocasting, squeeze casting and spray casting processes are liquid phase processes and friction stir processing and powder metallurgy are solid phase processes. Stir casting is effective in operation and cost saving and provides uniform distribution of nanoparticles. Powder metallurgy is an important process than others. It provides uniform distribution of particles but expensive than stir casting. The instrumentations such as (SEM) Scanning electron microscope, Transmission electron microscopy, (XRD) X-ray Powder Diffraction can be employed for evaluation of physical properties and microstructure characteristics and mechanical properties can be evaluated by tensile tests, hardness tests, impact tests, etc. Evaluation of other properties can be achieved by related suitable instrumentations

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